A Vision for Transforming Building Materials into Carbon Sinks

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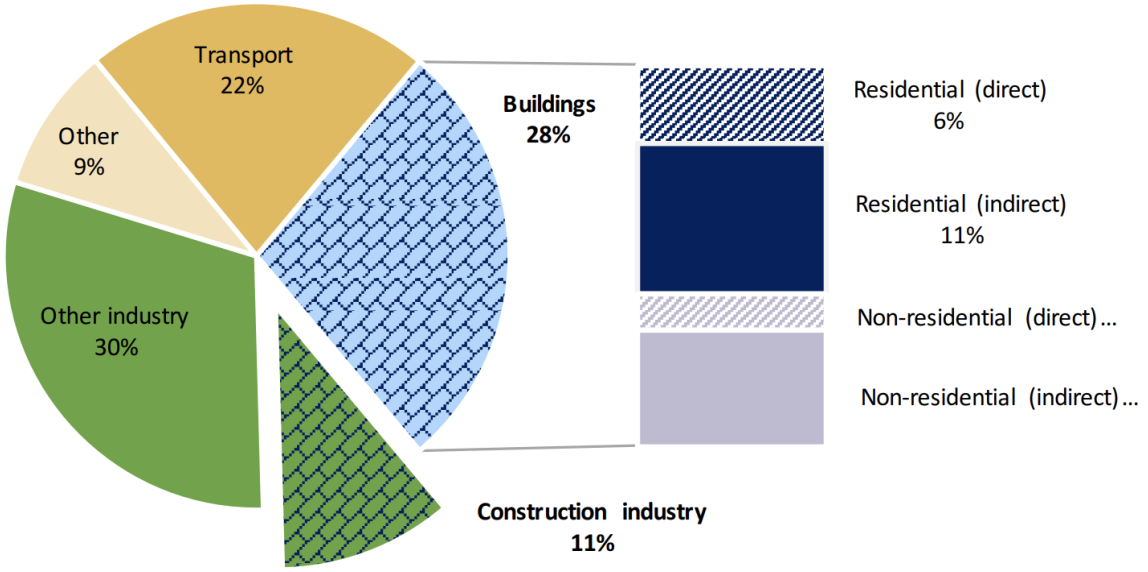
ARPA-E Carbon Negative Building Materials Workshop - Day 1

March 23, 2021

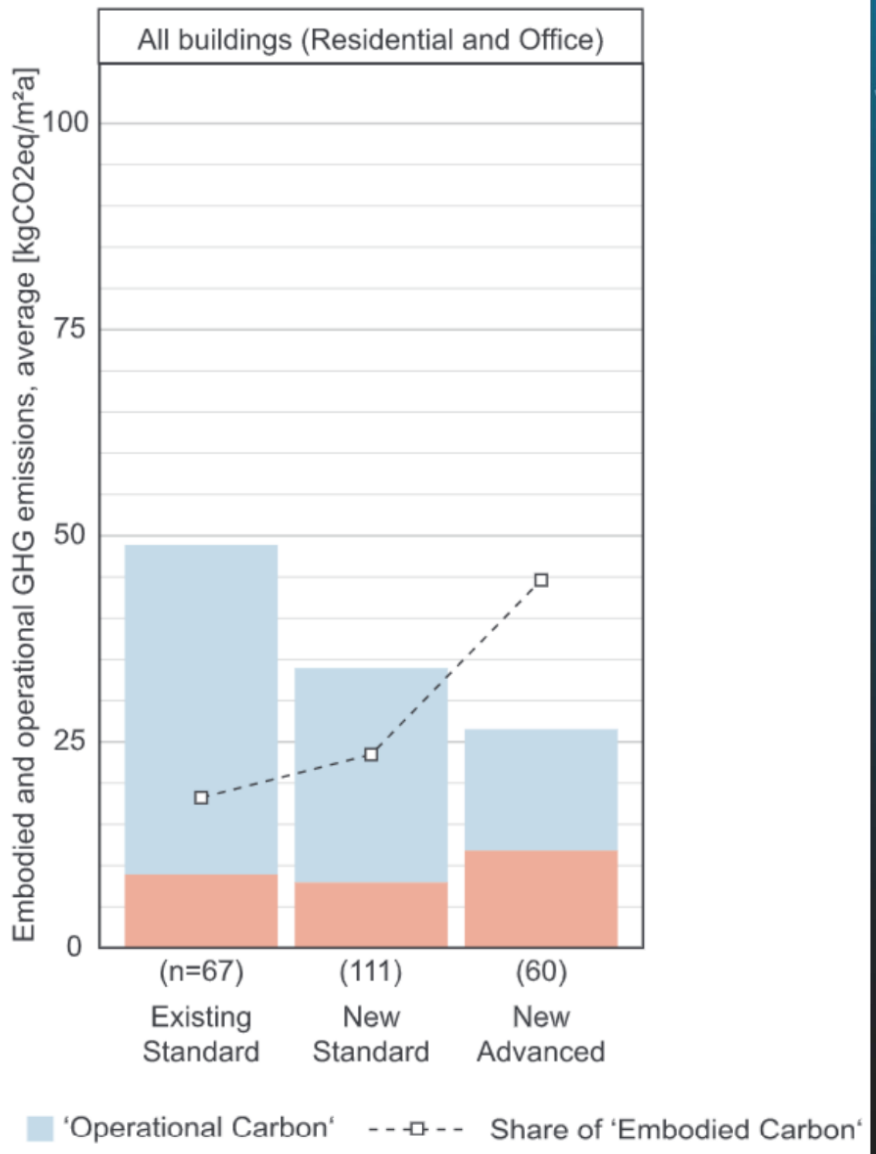
The Growing Importance Embodied Emissions

Share of global energy-related CO_2 emissions by sector, 2015



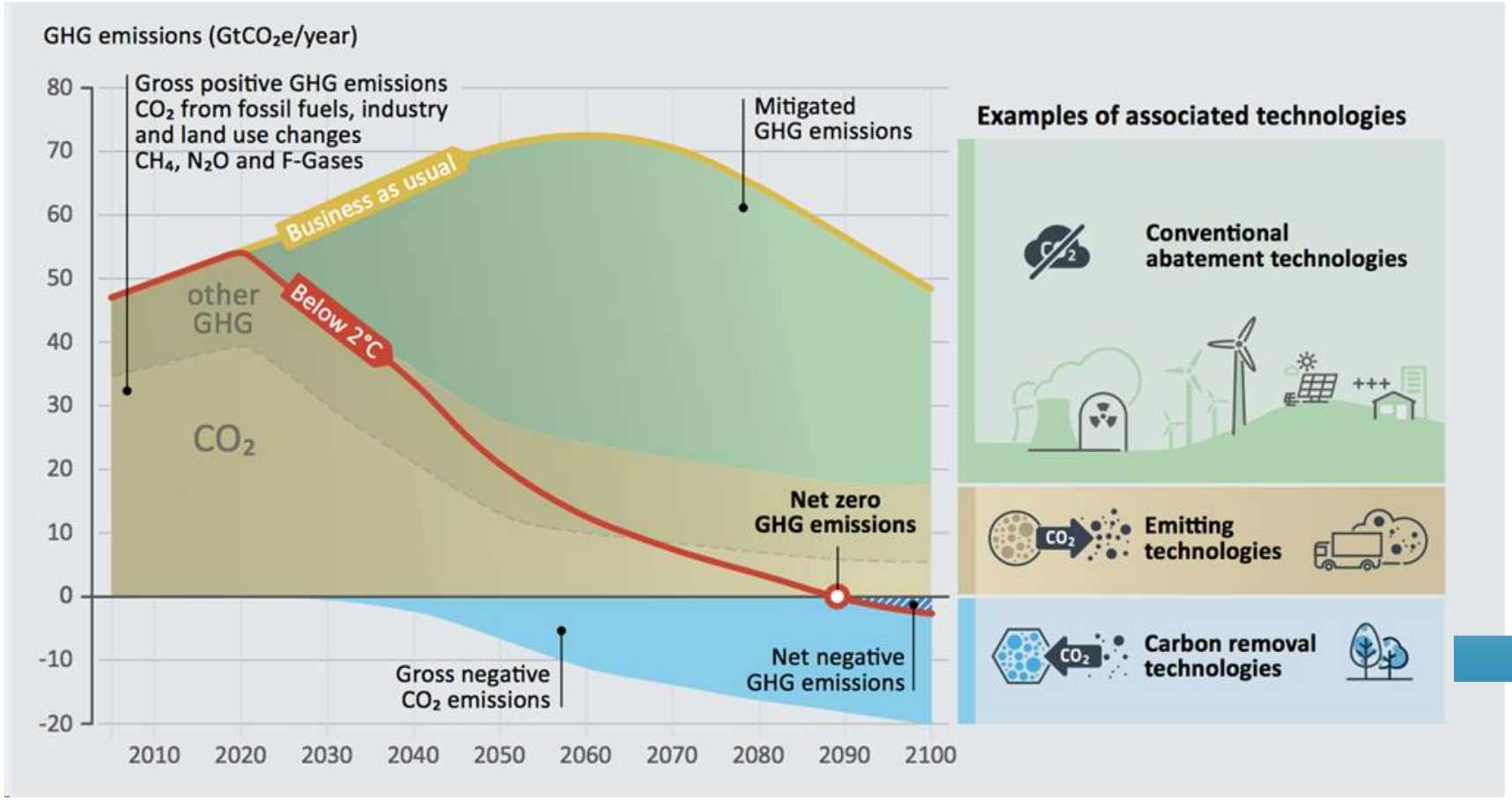
Source: 2018 UN Environment Global Status Report

- Overall amount from **operational emissions declines** w/ improved standards & total **embodied emissions increases** w/ production of higher performance materials
- Renovating, use of less materials, recycled or alternate materials are key, but more is necessary w/ **added population growth and new construction demands**



Source: Rock, M. et al., Applied Energy 258, 114107 (2020)

Expanding Carbon Utilization Approaches



Source: National Academy of Sciences. Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. 2019. p. 3

Opportunity for Buildings

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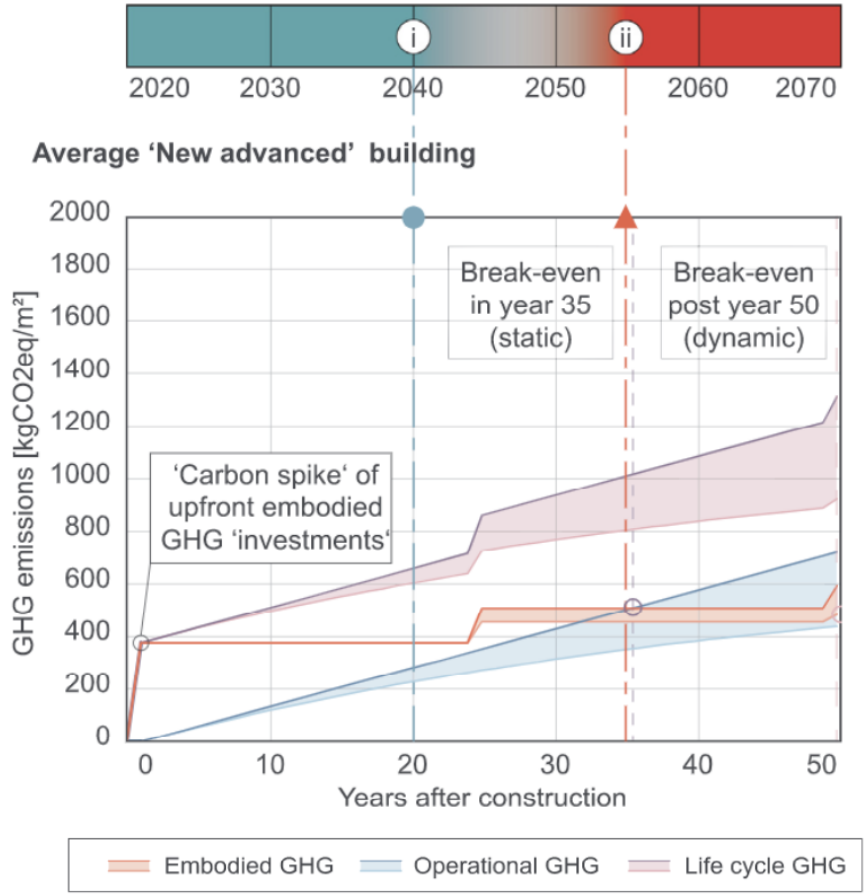
Program Vision

Transform our buildings into carbon sinks by:

- *reducing their embodied emissions*
- *expanding carbon utilization approaches*

So, Why Now?

- Developing carbon negative building materials is necessary now to enable future design decisions in lowering carbon to meet climate goals
- Embodied carbon gaining traction in the architecture, engineering, and construction (AEC) community
- An ARPA-E effort can spur further maturation of existing low carbon materials and exploration of new materials



Source: Rock, M. et al., Applied Energy 258, 114107 (2020)

architecture 2030 · 2030 PALETTE · mindful MATERIALS · ABC ADVANCED BUILDING CONSTRUCTION Collaborative · CLF Carbon Leadership Forum

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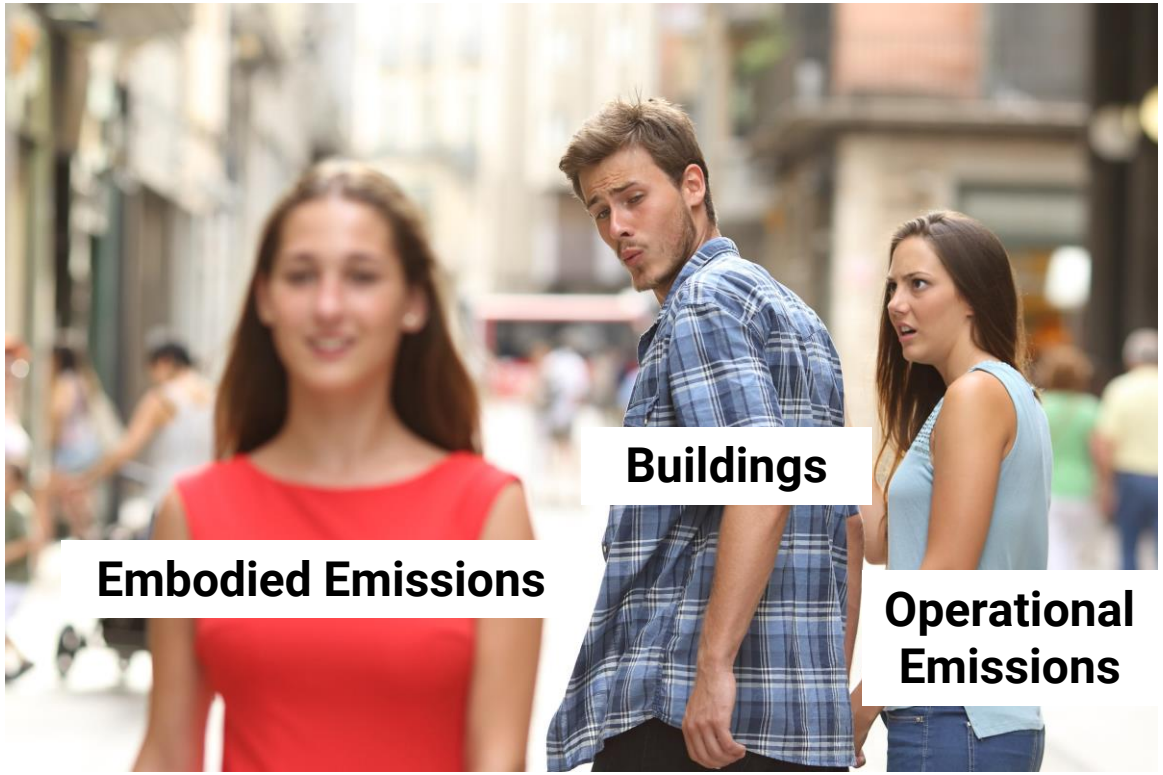
Reminder of Some Context



- **Embodied Emissions**:

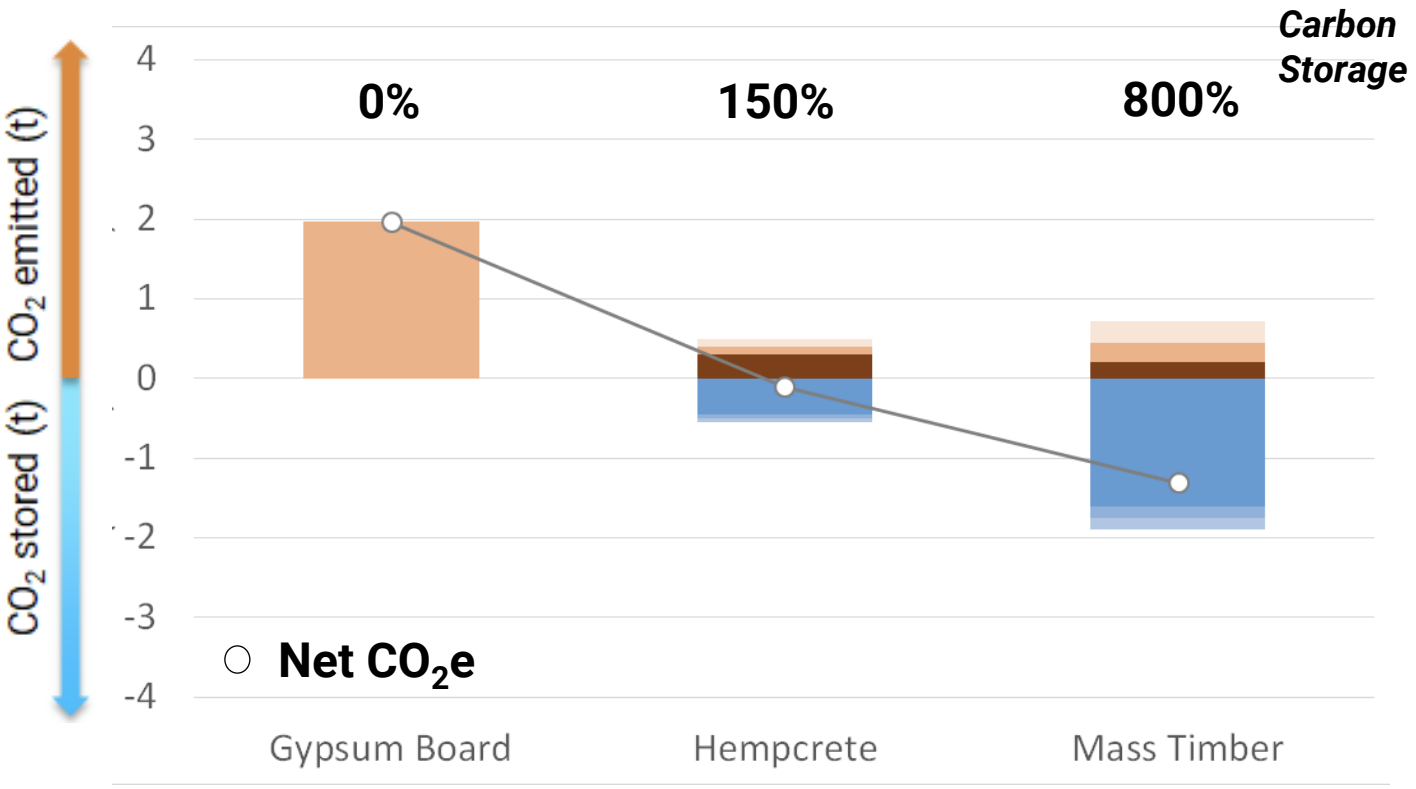
  GHG emissions associated w/ material manufacturing on a life-cycle basis

- **Embodied Carbon**:

  synonymous w/ embodied emissions, where carbon = CO_2 equivalents

While not the focus here, we don't want to sacrifice operational emissions in the process!

We're Starting from this Frame



- **Carbon Storage**:
  drawdown and retention of carbon in the form of CO_2 or CH_4
- **Carbon Negative:**
  negative = emissions – storage
- **% Carbon Storage:**
  = (storage / emissions) x 100

* Net CO_2e is difference between **mean** emissions estimate and **mean** storage estimate
CO_2e calcs from refs 1 & 2, based on emissions from: raw material supply, transport to factory, manufacturing, using standard LCA practices (system boundary A1-A3).

1. Pomponi and Moncaster, Renewable and Sustainable Energy Reviews (2017), DOI: 10.1016/j.rser.2017.06.049
2. Ruuska, "Carbon Footprint for building products." (2013), http://www.vtt.fi/publications/index.jsp

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Proposed Goals for this Potential Program

- Reduce life-cycle emissions by targeting embodied CO_2e associated with manufacturing building materials, while **maintaining/reducing operational energy** usage
- Manufacture building materials derived from GHG emissions to achieve at least **carbon neutrality** and **200% storage**
- Meet or exceed building construction and design specifications

Current Vision for this Potential Program

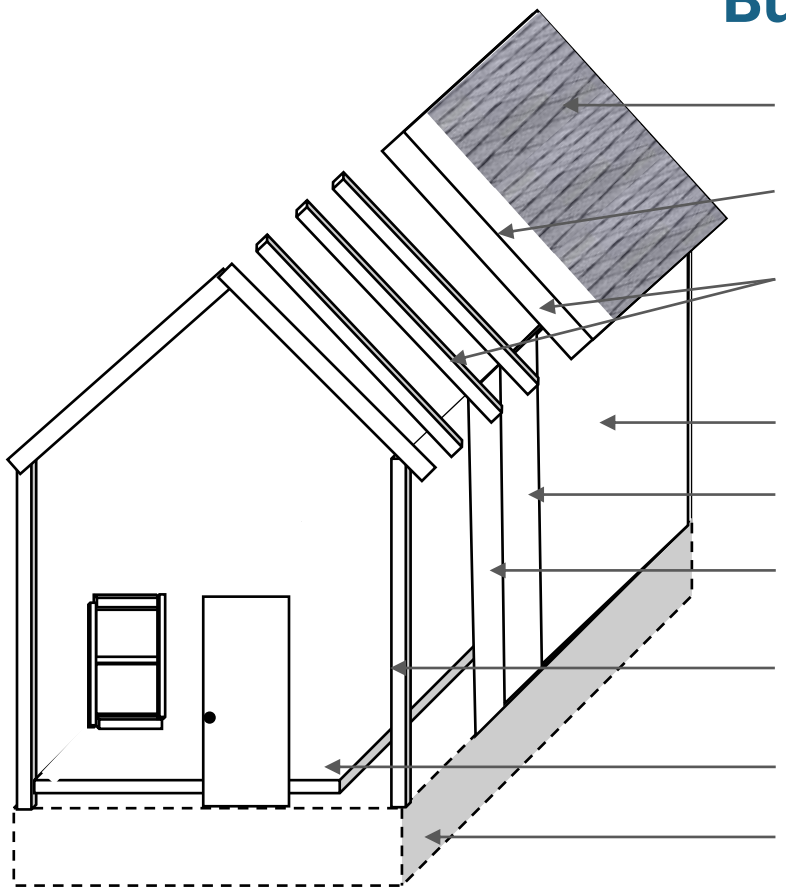
Develop materials that:

- Meet performance targets* for 1 or more incumbent building element(s)
- Achieve carbon negativity on life-cycle analysis basis (**A1-A3**)
- Demonstrate market adoption potential

Categories of Interest		
Building Elements	**Incumbent Building Materials**	**Feedstocks**
Foundation Framing Panels Insulation Siding Roofing , etc.	Concrete Steel Wood Polymers Masonry Brick	Ag (Straw, Hemp) Cork Cellulose Wood Stone / Rock Resin

***Performance metrics** based on applicable codes and related testing standards for incumbent material being replaced

Categories of Interest



Building Elements	Building Materials
Roofing	Fiber cement, metal, clay, asphalt
Roof insulation	Cellulose, fiberglass
Roof framing	Wood, steel, composite
Exterior cladding	Brick, vinyl siding, wood siding
Exterior insulation	Cellulose, fiberglass
Exterior sheathing	Wood, OSB
Wall framing	Wood, steel
Flooring	Wood, LVT, ceramic
Foundation	Wood, concrete, steel

- **Other options for organizing:** *Material Replacement, Feedstock*

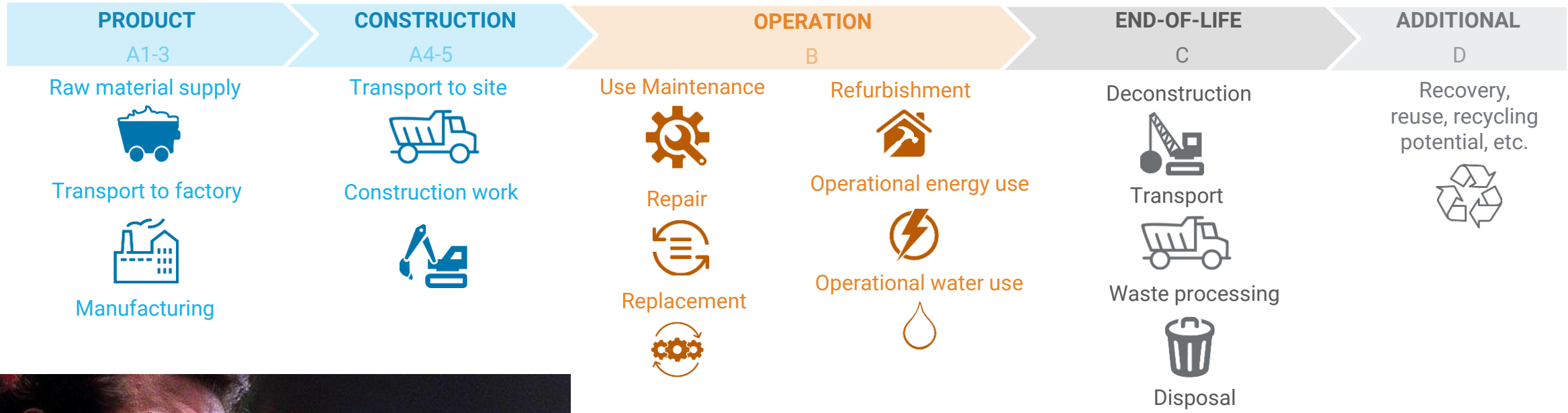
Developing Potential Program Metrics

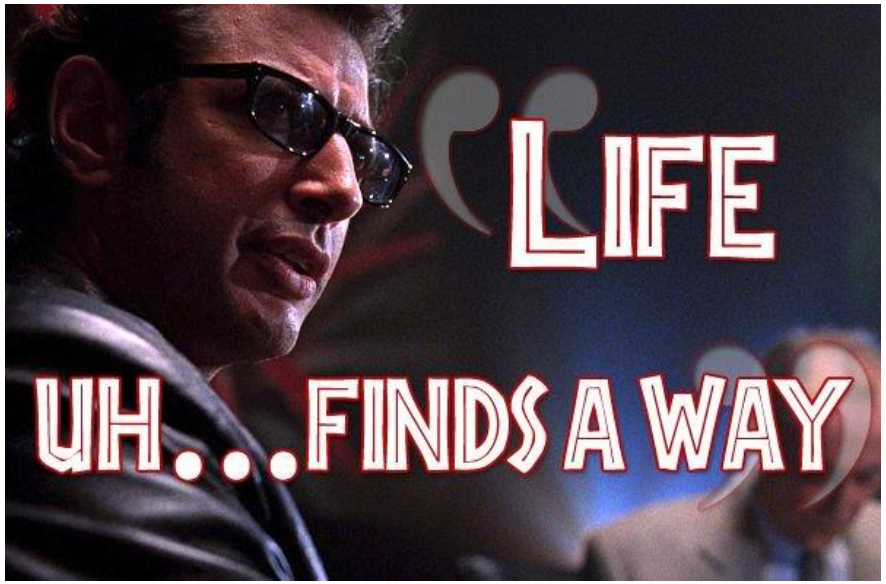
- **Objectives:**
  - Strike balance between achieving **carbon negativity vs. material performance**
  - Employ relevant metrics for **tomorrow's building materials**
  - Consider **path to market** (residential vs. commercial, new construction vs. retrofit)
- **Challenges:**
  - Performance requirements are building-type specific
  - Testing is often material-type specific

Category	For Consideration	Applicable Questions
Building Elements	Foundation, Framing, Insulation, Panels	• Are these the most impactful categories?
Performance Metrics – Primary	Safety and Service life	• What are the target values?
Performance Metrics – Secondary	Will vary by building type, element & material	• Testing prioritization? • What are the target values?

Bounds and Challenges for Life-Cycle Analysis (LCA)

- **Cradle-to-Grave Life Cycle Analysis for all Materials**

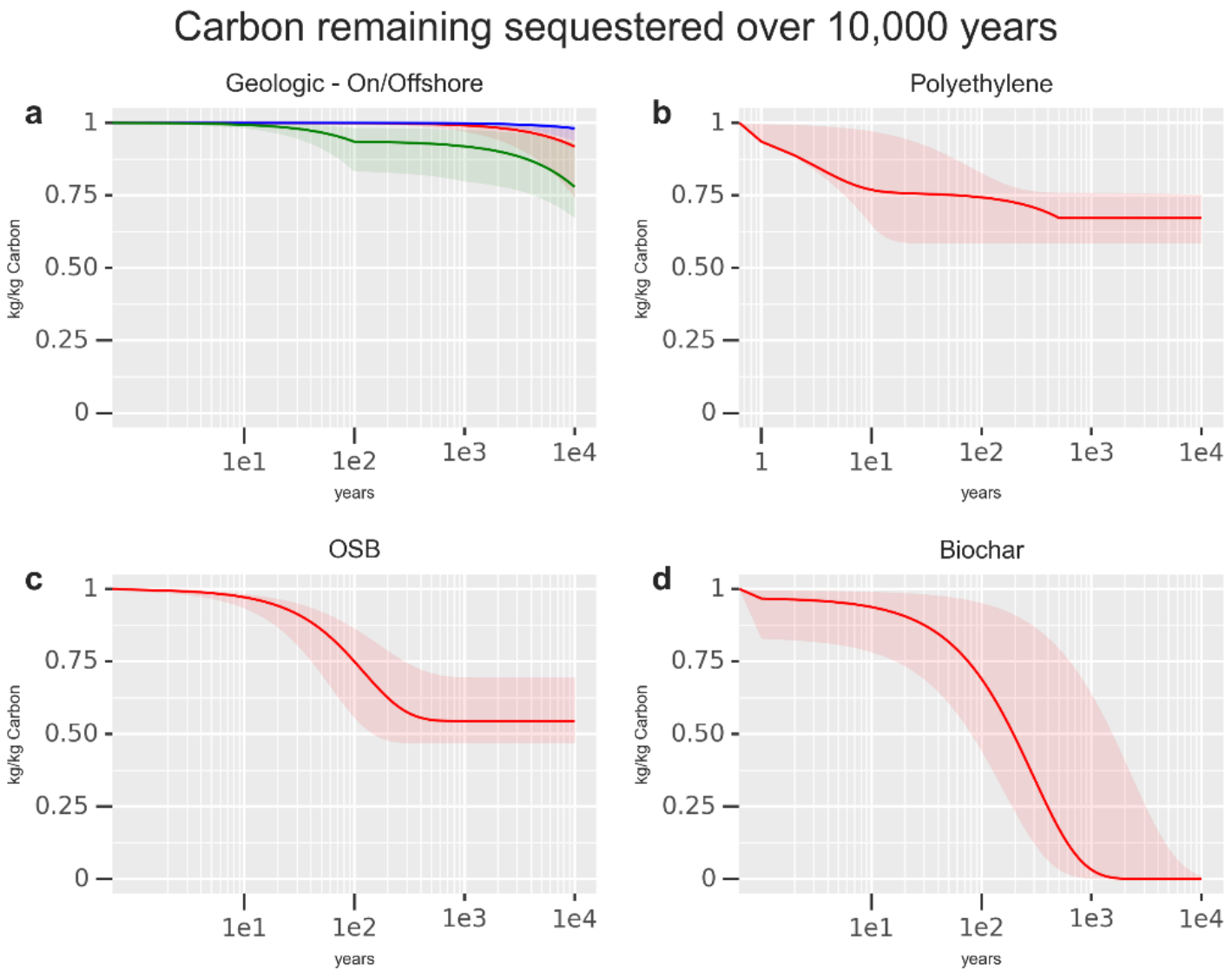




- **Challenges:**
  - Predicting end of life (EOL) scenarios & outcomes
  - Addressing / quantifying uncertainties
  - Validating and quantifying "permanent" carbon storage

Quantifying Carbon Storage Scenarios

- **Carbon release activity**
  - Need to account for wide variability in carbon release activity
- **Forecasting & validation**
  - What is an acceptable timeline for forecasting?
  - How does validation occur?
- **Recycling**
  - Recycling innovations out-of-scope
  - Using recycled materials that meet carbon storage metrics in-scope

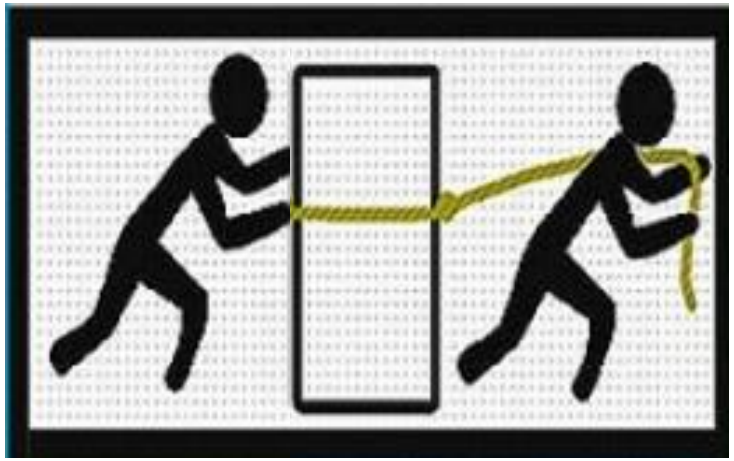


Reprinted from Analysis of the Bioeconomy for Carbon Drawdown. DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review. 2021

Path to Market: Building Code Adoption Routes

Pro

Codes today include operational energy usage



Con

Codes today do not consider embodied carbon

Opportunity

Consider embodied carbon while meeting/exceeding operational energy requirements

While Important, Not in Scope for This Potential Effort

- Development of low-carbon, embodied carbon **policies**
- Updates to/adoption of new building **codes**
- Development of new **testing** specifications
- Innovations in **construction** methods and practices
- Establishment of new **LCA methods and tools**

What We Want from You Today and Thursday

- **Shape potential program/FOA structure:**
  - Establish the **most impactful categorization** to achieve emission reduction & carbon drawdown goals
  - Identify any **critical technologies/pathways** that are missing
  - Prioritize **key metrics** that are ambitious, yet achievable for program success (R&D needs)

- **Stakeholder Outreach:**
  - Spread the word that ARPA-E is interested in this area!
  - Identify critical expertise not currently on our radar

- **Networking/Team Building:**
  - Facilitate connections across the technology development pipeline for potential project teaming

Be bold and think big!

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Rest of Day 1 Agenda – Objective: Establishing the Framework

1:15 – 1:35 PM	**Importance of Embodied Carbon** *Kate Simonen, Carbon Leadership Forum*	
1:35 – 1:50 PM	**Break**	
1:50 – 2:10 PM	**Decision Making for Lowering Embodied Carbon** *Scott Schneider & Pawel Woelke, Thornton Tomasetti*	 
2:10 – 2:30 PM	**Routes to New Materials and Codes** *Anica Landreneau, HOK*	
2:30 – 2:50 PM	**Knowing the Value of a Material** *Hao Cai, Argonne National Laboratory*	
2:50 – 3:10 PM	**Carbon-Storing Material Technologies: The Current Landscape** *Wil Srubar III, University of Colorado Boulder and Aureus Earth, Inc.*	
3:10 – 3:20 PM	**Break**	
3:20 – 4:30 PM	**Breakout Sessions Day 1**	
4:30 – 5:00 PM	**Breakout Sessions Report Out and End of Workshop Day 1 Wrap-up** *Marina Sofos, ARPA-E*	

Day 2 Agenda Preview - Objective: Technical Deep Dives

12:00 – 12:20 PM	**Day 1 Summary and Day 2 Objectives** *Marina Sofos, ARPA-E*
12:20 – 12:30 PM	**Introduction to ARPA-E Tech-to-Market** *Madhav Acharya, ARPA-E*
12:30 – 1:30 PM	**Products to Market Panel** *Moderator: Josh Agenbroad, Rocky Mountain Institute* *Ryan Spies, Saint-Gobain* *Jerry Uhland, CalPlant* *Michael Dosier, bioMASON* *Kaustubh Pandya, Brick & Mortar Ventures*
1:30 – 1:40 PM	**Break**
1:40 – 2:00 PM	**Uses of Agricultural and Forestry Products in Thermosetting Polymers** *Dean Webster, North Dakota State University*
2:00 – 2:20 PM	**Lignin-Based Carbon Materials – Potential High Value and High Volume Applications** *Zhiyong Cai, USDA Forest Products Laboratory*
2:20 – 2:40 PM	**mycotecture: shaping the built environment with mycelium** *Christopher Maurer, redhouse*
2:40 – 3:00 PM	**Reduce and Recapture CO2: Sustainable Approach for Macro- and Nano-Scale Carbon in Building Materials** *Anna Douglas, SkyNano* *Hicham Ghossein, Endeavor Composites*
3:00 – 3:15 PM	**Break**
3:15 – 4:30 PM	**Breakout Sessions Day 2**
4:30 – 5:00 PM	**Breakout Sessions Report Out and Workshop Closing Remarks** *Marina Sofos, ARPA-E*

Today's Breakout Sessions

LCA and Tools

Facilitator: Doug Wicks

Notetaker: Laura Demetrion

Chat Moderator: Christina Chang

Markets and Drivers

Facilitator: Marc von Keitz

Notetaker: Rose Cox-Galhotra

Chat Moderator: Emily Yedinak

Metrics and Codes

Facilitator: Scott Litzelman

Notetaker: Kalena Stovall

Chat Moderator: Ian Robinson

Category Comparison #1

Facilitator: Dave Babson

Notetaker: Kate Pitman

Chat Moderator: Elizabeth Troein

Category Comparison #2

Facilitator: Madhav Acharya

Notetaker: Jared Incorvati

Chat Moderator: Grace Ryan

THANK YOU!

Marina Sofos, Madhav Acharya
Advanced Research Projects Agency-Energy

Kate Pitman, Kalena Stovall
Booz Allen Hamilton

15 min. meeting slots available with ARPA-E team for this Friday 1-4 pm ET; Link to book will be circulated to attendees via e-mail after today's sessions